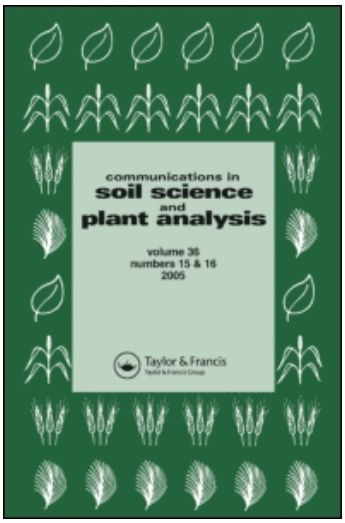

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Soil Organic Carbon and Nitrogen Fractions in Temperate Alley Cropping Systems

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Soil Organic Carbon and Nitrogen Fractions in Temperate Alley Cropping Systems

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Abstract: Alley cropping may promote greater sequestration of soil organic carbon. The objective of this study was to examine spatial variability of soil organic carbon (C) and nitrogen (N) fractions relative to tree rows in established alley cropping systems in north central Missouri. Soils were collected to a depth of 30 cm from two alley cropped sites, a 19-yr-old pecan (*Carya illinoinensis*)/bluegrass (*Poa trivialis*) intercrop (pecan site) and an 11-yr-old silver maple (*Acer saccharinum*)/soybean (*Glycine max*)–maize (*Zea mays*) rotation (maple site). Particulate organic matter (POM) C constituted 15–65% and 14–41% of total organic C (TOC) at the pecan and maple sites respectively, whereas POM N comprised 3 to 24% of total N (TKN). TOC and TKN were on average 13% and 18% higher at the tree row than at the middle of the alley for surface soils (0–10 cm) at the pecan site, respectively. Similarly, POM C was two to three times higher at the tree row than the alley for sub-surface soils at the maple site. No differences in microbial biomass C and N between positions were observed. Observed results suggest the existence of spatially dependent patterns for POM C, TOC, and TKN, relative to tree rows in alley cropping.

Keywords: Microbial biomass, mineral associated organic matter, particulate organic matter, pecan, silver maple

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INTRODUCTION

Agroforestry has been proposed as one strategy to mitigate increasing CO_2 levels in the atmosphere (IPCC 1995) and has potential to sequester carbon (C) by increasing C storage in aboveground perennial components (Kort and Turnock 1999) and in soil (Marquez et al. 1999). In alley cropping, trees or woody shrubs are established in rows with crops planted between the tree rows (Rosecrance, Brewbucker, and Fownes 1992). This agroforestry practice may introduce differential sequestering of soil C because of the microclimate created by the trees and disparity in litter characteristics and amounts between the trees and intercrops.

Variations in soil temperature and soil water may affect soil microbial dynamics, leading to altered soil processes and properties relative to the location of trees. Tree canopies usually reduce soil temperatures (Belsky et al. 1993; Feldhake 2001), while the effect on soil moisture may vary. Belsky et al. (1993), for example, reported reductions in maximum soil temperature of about 5–12°C under isolated trees in savannah regions, while soil water content was similar under tree canopies and open grasslands. In contrast, soil water content was significantly lower under trees than in the cropped area in a silver maple–maize alley cropping system (Miller and Pallardy 2001).

Localized plant inputs enhance soil organic matter (SOM) levels under plants compared to plant interspaces (Hook, Burke, and Lauenroth 1991). Total soil organic C (TOC) and total nitrogen (N) are the main components of SOM, making up approximately 58 and 20% of the total weight of SOM, respectively (Brady and Weil 2002). Different approaches have been used to understand SOM dynamics, such as partitioning SOM into fractions based on biological lability with different turnover rates related to certain ecosystem functions (Schroth, Vanlauwe, and Lehman 2003). One approach is separation of SOM into particulate organic matter (POM) and mineral-associated (Ma) organic matter by chemical dispersion of soil followed by physical separation based on particle size (Cambardella and Elliott 1992). POM C has been shown as the C fraction that is preferentially lost when soils are subjected to conventional cultivation (Cambardella and Elliott 1992; Chan 2001). Marquez et al. (1999) found that POM C was significantly higher in 7-yr-old riparian buffers with perennial vegetation (poplar tree, cool season grass, and switch grass) than in cultivated systems. Research indicates that POM C is one of the more labile C fractions and may be more sensitive to changes in TOC.

Microbial biomass is the living component of soil organic matter, with a turnover time of less than 1 yr (Paul 1984) and, similar to POM, may rapidly change in response to modifications in environmental conditions. Chander et al. (1998) reported significantly higher microbial biomass C in treatments that included 12-yr-old *Dalbergia sissoo*, a nitrogen-fixing tree, compared to a wheat–cowpea control in a tropical alley cropping system. These

authors attributed the higher microbial biomass to increased organic input through tree prunings. TOC in the same study was not consistently higher in all treatments that included the trees, showing that microbial biomass responded more quickly to organic inputs.

Differences in the rate of litter decomposition can lead to large differences in organic matter accumulation and the C and N content of soils (Parton et al. 1987). Lee and Jose (2003) reported a threefold higher leaf litter biomass in a 47-yr-old pecan–cotton alley cropping system compared to the monocropped cotton. They also observed higher microbial biomass C and soil organic matter in the alley cropped plots than in monoculture cotton. The objective of this study was to examine spatial and temporal variability of soil organic C and N fractions in established alley cropping practices in north central Missouri. It was hypothesized that soil C and N fractions would differ between the tree row and the middle of the alley because of differences in microclimate and litter characteristics between the tree and intercropped components.

MATERIALS AND METHODS

Experimental Sites and Soil Sampling

Two sites in north central Missouri with mature trees were selected for this study. Table 1 shows a summary of site characteristics. At the pecan site, pecan trees were planted in 1981 in rows spaced 12 m apart with 4.5 m between each tree in the row, in a south–north orientation. The trees were intercropped with a maize–soybean–wheat rotation for the first 11 yr, after which the trees were thinned to a spacing of 12 m × 9 m and bluegrass was planted in the alleys. In 1999, the pecan site received broadcast applications of lime at 6.2 t ha^{-1} and N fertilizer at 35 kg N ha^{-1}. Weed control under trees was by spot spraying with atrazine, whereas the alleys were mowed and bluegrass removed for hay at least once a year. The soil is classified as a Gosport silty clay loam (fine, illitic, mesic Typic Dystrochrepts). Mean annual temperature and precipitation for this site are 13°C and 850 mm, respectively.

At the maple site, silver maples were planted in 1990 in rows spaced 18 m apart with a 1.5-m distance between each tree within the row. Tree rows were in an east–west orientation and intercropped with a maize–soybean rotation under no-till management. In 1996, silver maples were thinned based on stem form. Maize was planted at 70,000 seeds ha^{-1} as the intercrop in 2000 and 2002. Soybeans were planted at 500,000 seed ha^{-1} in 2001. Weed control was by a spray application of glyphosate, ammonium sulfate, and 2, 4-D. In fall 2001, 20, 39, and 93 kg ha^{-1} of N, phosphorus (P), and potassium (K) fertilizer, respectively, were applied and another 130 kg N ha^{-1} in 2002. Mean annual temperature and precipitation at this site are 12°C and 760 mm, respectively. The soil is classified as a Mexico silt loam (fine, smectic, mesic Aeric Vertic Epiaqualfs).

Table 1. Selected site characteristics of two temperate alley cropping systems

Parameter	Site	
	Pecan	Maple
Latitude/longitude (degrees, minutes)	39°4′ N, 92°7′ W	39°58′ N 92°5′ W
Age of trees (yr)	21	12
Trees (no. ha^{-1})	289	370
Mean tree height (m)	7 ± 1[a]	12 ± 1
Mean DBH[b] (cm)	17 ± 2	24 ± 2
Tree leaf amounts (kg ha^{-1})	1323	2942
Other components, litter amounts (kg ha^{-1})	2000 (bluegrass)	3000 (soybean) 5000 (maize)
Tree leaf litter, C:N ratio	32 ± 3	45 ± 7
Other components, C:N ratio	19 ± 1 (bluegrass)	20 ± 4 (soybean) 28 ± 2 (maize)
Mineral soil (0–20 cm)		
Textural class	Silty clay loam	Silt loam
Clay (%)	27.6	24.9
Silt (%)	62.4	70.3
Sand (%)	10.0	4.7
pH (1:1 $CaCl_2$)	6.3 ± 0.1	6.7 ± 0.1
Total organic C (%)	1.2 ± 0.2	1.8 ± 0.1
Total N (%)	0.08 ± 0.01	0.16 ± 0.01
C:N ratio	15 ± 4	12 ± 1

[a]Values show $\pm$ one standard deviation.
[b]Measurement of tree trunk at breast height.

Soils were sampled using a 2-cm-diameter stainless steel push probe at 0 (tree row), 1.5, 3.0, 4.5, and 6.0 m (middle of the alley) from the tree row at the pecan site and at 0, 3.0, 6.0, and 9.0 m at the maple site. Sampling was done at depths of 0–10, 10–20, and 20–30 cm at each position. At each sampling position, five to six cores were taken and composited to yield one sample. Five locations were sampled at each site in fall 2001 and summer 2002. One half of each soil sample was air dried, ground, and passed through a 2-mm mesh sieve for chemical analysis and the other half was maintained field moist and stored at 4°C for soil microbial biomass analysis. Stored soils were preincubated at room temperature (25–27°C) for 24 h before analysis commenced. Results reported in this article show comparisons of the tree row and middle of the alley positions because differences between the other positions were minimal.

Litter amounts in the two sites were estimated using 1 m × 1 m × 0.15 m litter traps raised to 1 m high. Litter was collected monthly from the traps

from August through November of 2001; average results are reported in Table 1. Additionally, crop residue amounts were estimated from 1 m × 1 m quadrants.

Incubation

Carbon and N mineralization were measured using an aerobic leaching incubation procedure (Motavalli, Frey, and Scott 1995) for N mineralization, modified to simultaneously take CO_2 measurements. Bulk soils were collected to a depth of 20 cm from the two sites. Pecan, bluegrass, maple, soybean, and maize litter were used for incubation in a completely randomized design with four replications. Fifty grams of soil amended with 150 mg of ground litter were mixed with 50 g of acid-washed sand and put in Falcon filter units (150-mL bottle-type, Becton Dickinson Labware, NJ, USA). The filter units were initially leached with 100 mL of N-free nutrient solution (Nadelhoffer 1990) under 47-kPa suction for 1 h. Subsequent leachings were with 50 mL of N-free nutrient solution. After initial leaching, the filter units were enclosed in 1.9-L polyethylene tetraphthalate jars (Cole-Parmer P-06043-75) along with a vial containing 1 *M* NaOH and incubated at 25°C. The filter units were periodically leached after 1, 2, 3, 4, 8, 12, 19, 25, 34, and 45 weeks of incubation. The leachates were collected and analyzed for NH_4^+-N and NO_3^--N using a Lachat Quikchem Analyzer (Zellweger Analytics 1996a). The NaOH traps were removed at each sampling time, and CO_2 was determined by back titration with 0.5 *M* HCl after adding 10 mL of 1.5 *M* $BaCl_2$.

Laboratory Analysis

A heated potassium dichromate oxidation was used to analyze TOC (Nelson and Sommers 1986). Soil total N was determined by Kjeldahl digestion, and NH_3 in the digest was measured using a Lachat QuikChem Automated Ion Analyzer (Zellweger Analytics 1996b). Particulate organic matter was determined by a wet sieving method (Cambardella and Elliot 1992). Ten grams of soil were dispersed with 30 mL of 5 g L^{-1} sodium hexametaphosphate by shaking for 18 h. The dispersed soil was passed through a 53-μm sieve, and both the material that passed through the sieve (Ma) and that remained on the sieve (POM) were oven dried at 65°C. TOC and total N were determined in each fraction. TOC was analyzed by a modified dry combustion method (Soil Survey Lab. Manual 1996) and total nitrogen by Kjeldahl digestion. Microbial biomass C and N were determined by the chloroform fumigation extraction method (Rice, Moorman, and Beare 1996), with k values of 0.41 and 0.68, respectively. TOC and total N of the 0.5 *M* K_2SO_4 extract for the unfumigated samples are referred to as soluble C and N respectively. Calculation of data on a per hectare basis is based on measured bulk

densities. Bulk densities were determined using an Uhland probe and the core method (Blake and Hartge 1986).

Statistical Analysis

All statistical procedures were performed using the SAS statistical program (SAS Institute 2001). The t-test was used to test for differences between positions in the alley using input data sets of summary statistics. Pearson linear correlation analysis (PROC CORR) was performed to determine relationships among some of the soil properties analyzed.

RESULTS

Total Organic Carbon and Nitrogen

TOC was higher at the tree row than in the alley at 10-cm and 30-cm depths in 2001 at the pecan and maple sites, respectively (Table 2). In 2002, TOC was

Table 2. Soil total organic C and total N in relation to tree row position in two temperate alley cropping systems in 2001 and 2002

Soil property	Total organic carbon (%)			Total Kjeldahl nitrogen (%)			C:N ratio		
Depth (cm)	10[a]	20	30	10	20	30	10	20	30
2001									
Pecan tree[b]	1.92	1.34	1.31	0.16	0.09	0.08	11.8	15.7	20.4
Pecan mid	1.62	1.39	1.33	0.14	0.09	0.08	11.6	15.4	17.4
$P > \|t\|$	*	NS	NS	**	NS	NS	NS	NS	NS
Maple tree	1.45	1.48	1.27	0.18	0.15	0.14	8.8	10.0	9.2
Maple mid	1.62	1.36	0.88	0.16	0.13	0.11	8.8	11.5	8.0
$P > \|t\|$	NS	NS	***	*	NS	***	NS	NS	NS
2002									
Pecan tree[b]	2.09	1.33	1.18	0.18	0.11	0.10	11.4	11.6	12.2
Pecan mid	2.00	1.25	1.16	0.16	0.11	0.10	12.4	11.6	11.9
$P > \|t\|$	NS	NS	NS	*	NS	NS	NS	NS	NS
Maple tree	1.95	1.56	0.99	0.19	0.15	0.11	10.3	10.2	9.0
Maple mid	1.83	1.22	0.92	0.18	0.13	0.10	10.2	9.6	9.1
$P > \|t\|$	NS	***	NS	NS	***	*	NS	NS	NS

[a]10, 20, and 30 represent sampling depths at 0–10, 10–20, and 20–30 cm, respectively.

[b]Tree and mid represent tree row and middle of alley, respectively.

*, **, and *** represent significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively, using the t-test. NS is not significant.

similarly higher at the 20-cm depth at the maple site. For total N (TKN) at the pecan site, differences were observed only for surface soils (0–10 cm), where the tree row had 12–14% more N than the middle of the alley in the two years. Similarly, TKN was higher at the tree row for surface soils and at 30-cm depth in 2001 and at 20- and 30-cm depths in 2002 at the maple site (Table 2). TOC and TKN decreased with depth and both were positively correlated at the two sites (Table 3).

Soil C:N ratios ranged from 11.4 to 20.4 at the pecan site and increased with depth. At the maple site, C:N ratios were lower and ranged from 8.0 to 11.5, with the highest values at the 20-cm depth (Table 2). Overall, soil C:N ratios did not differ with positions in the alley.

Particulate and Mineral Associated Organic Matter

Mineral-associated organic C (Ma C) was lower at the tree row than in the alley at 20-cm depth at the pecan site (Figure 1). However, no differences were observed between the tree row and the middle of the alley for POM C, POM N, and Ma TN (Figure 1). Similarly, differences in Ma C and Ma TN were minimal at the maple site (Figure 2). POM C and N were consistently higher at the tree row than at the middle at 20- and 30-cm depths (Figure 2). Additionally, although no differences were observed in POM C between the two sampling times at both sites, POM N increased by 87 and

Table 3. Pearson correlation coefficients (r) for soil organic matter fractions at the pecan and maple sites for all depths and sampling times combined, n = 60

SOM fraction	TOC[a]	TKN	POM C	POM N	Ma C
Pecan site					
TKN	0.66***				
POM C[b]	0.41***	0.77***			
POM N	0.56***	0.72***	0.66***		
Ma C	0.56***	0.38**	0.53***	0.04	
MaTN	0.49***	0.37**	0.36**	0.09	0.34**
Maple site					
TKN	0.89***				
POM C	0.79***	0.81***			
POM N	0.75***	0.82***	0.88***		
Ma C	0.26	0.23	0.17	0.09	
MaTN	0.69***	0.67**	0.58***	0.59***	0.17

[a]TOC is total organic carbon, TKN is total Kjeldahl nitrogen, POM is particulate organic matter, MaOC is mineral-associated organic carbon, and MaTN is mineral-associated total nitrogen.

[b]For POM C, n = 48.

, * represent significance at $P < 0.01$ and $P < 0.001$, respectively.

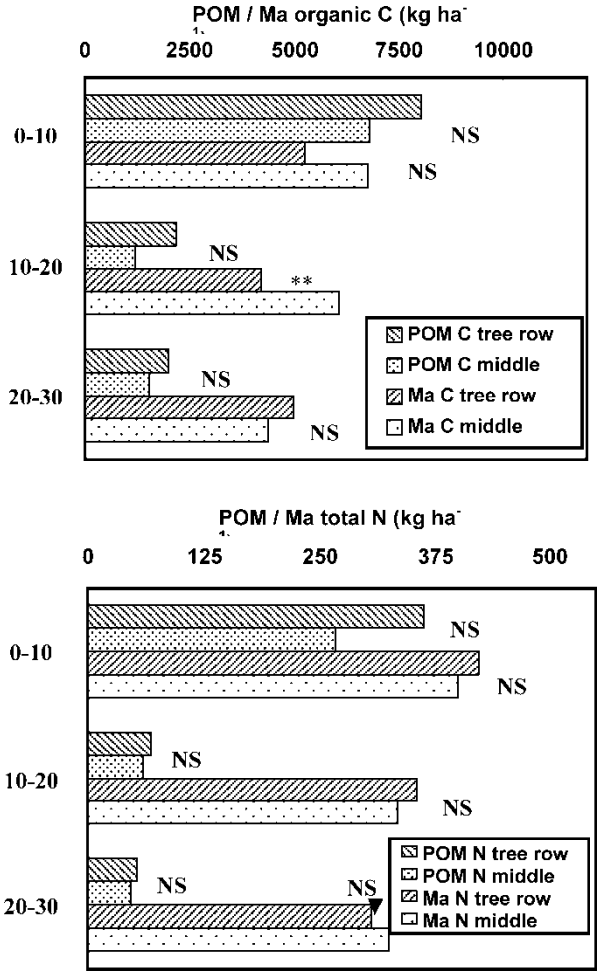

Figure 1. Spatial patterns of (a) particulate organic matter (POM) and mineral-associated (Ma) organic C, and (b) POM and Ma total N for soils sampled in fall 2001 at the pecan site. ** Represents significance at $P < 0.01$ using the t-test.

84 kg ha^{-1} at the 20-and 30-cm depths, respectively, at the pecan site. Ma TN increased by 88 and 98 kg ha^{-1} at the 20-and 30-cm depths at the pecan site and by 141 kg ha^{-1} at the 30-cm depth at the maple site.

POM C and N decreased with depth at both sites whereas Ma C and TN had no significant differences with depth (Figures 1 and 2). POM C for surface soil (0–10 cm) constituted 15 to 65% and 14 to 41% of soil total C, and for subsurface soil, POM C represented 3 to 24% and 3 to 26%, at the pecan and maple sites, respectively. POM N expressed as percent of TKN ranged from 3 to 24% and was generally lower at the maple site than at the pecan site.

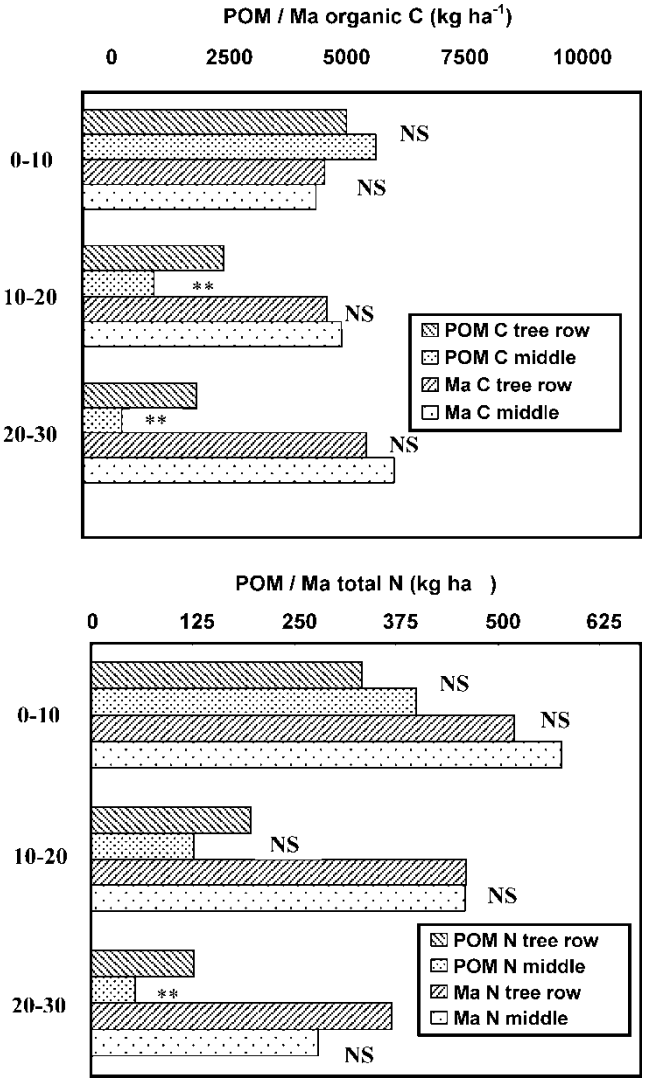

Figure 2. Spatial patterns of (a) particulate organic matter (POM) and mineral-associated (Ma) organic C, and (b) POM and Ma total N for soils sampled in fall 2001 at the maple site. ** Represents significance at $P < 0.01$ using the t-test.

POM C and N were highly correlated at the two sites (Table 3). Additionally, POM C and N were positively correlated to TOC and TKN (Table 3). Ma C was not correlated to any of the other fractions at the maple site (Table 3) and, together with Ma TN, generally had weaker correlations with other fractions at the pecan site.

Microbial Biomass

Overall, no differences were observed between the tree row and the middle of the alley in microbial biomass C and N (Table 4). Microbial biomass C:N ratio ranged from 1.7 to 9.9 with an average of 6.0 (Table 4). MB C and N generally decreased with depth.

Microbial biomass C constituted 1 to 2% of soil C at both sites, whereas MBN varied from 2 to 10% of soil total N. Generally, the pecan site had higher amounts of MBC than the maple site, and the maple site had higher MBN (Table 4).

DISCUSSION

Accumulation of TOC in soil is closely related to plant biomass additions (Burket and Dick 1997), with increased biomass leading to an increase in TOC. In an alley cropping system, C inputs include leaf and root litter from the tree and the intercropped components. Aboveground litter inputs into the two alley cropping systems are shown in Table 1. Although litter inputs into the middle of the alley are higher at the two sites, the authors observed that tree leaf litter was more scattered in the farms than initially predicted, complicating litter amounts comparisons and possibly explaining lack of consistent differences in TOC. Additionally, at the pecan site, there was a continuous cover of bluegrass under the trees, minimizing differences in litter amounts. Belowground litter contribution was not quantified and may have influenced the TOC values observed.

TOC contents are usually higher on the soil surface especially on no-till soils (Franzluebbers, Hons, and Zuberer 1995), and our results confirm this. Similarly, Finzi, Van Breemen, and Canham (1998) observed no differences in TOC at the 7.5-cm depth under canopies of five hardwood species (white ash, red maple, sugar maple, beech, and red oak) in northeastern Connecticut, but these authors reported decreasing TOC amounts with depth. Accumulation of TOC on the surface at the pecan site may have resulted from the continuous supply of C provided by bluegrass and pecan roots.

Although TKN accumulation has been related to plant biomass inputs, it can also be modified by vegetation type and N fertilization. Observed results for higher TKN at the tree row for surface soils at the pecan site may be related to differences in C and N mineralization of pecan and bluegrass litter. Microcosm studies showed that bluegrass litter mineralized significantly higher amounts of C than pecan leaf litter (Figure 3), but no differences were observed in cumulative N mineralized (Figure 3). Increased mineralization of C may lead to soil organic matter with a narrow C:N ratio that would favor N accumulation. At the maple site, TKN may have accumulated by a slightly different mechanism. Similar microcosms studies showed no differences in C mineralized among maple, soybean, and maize residues

Table 4. Soil microbial biomass C and N for soil sampled in summer 2002 from two temperate alley cropping systems

Location	MBC[a] (kg ha^{-1})	MBN (kg ha^{-1})	MBC as % of TOC	MBN as % of TKN
0–10 cm				
Pecan row[b]	363	57	1.5	2.7
Pecan mid	357	49	1.3	2.2
$P > \|t\|$	NS	NS	NS	NS
Maple row	245	145	1.3	9.5
Maple mid	305	146	1.7	9.7
$P > \|t\|$	NS	NS	NS	NS
10–20 cm				
Pecan row	246	29	1.6	1.9
Pecan mid	149	24	1.1	1.5
$P > \|t\|$	NS	NS	NS	NS
Maple row	205	40	1.7	2.7
Maple mid	116	30	0.5	1.7
$P > \|t\|$	NS	NS	NS	NS
20–30 cm				
Pecan row	199	22	1.1	1.4
Pecan mid	131	22	1.1	1.7
$P > \|t\|$	NS	NS	NS	NS
Maple row	145	25	0.8	1.8
Maple mid	197	20	1.1	1.0
$P > \|t\|$	NS	NS	NS	NS

[a]MBC, MBN, Sol C, and Sol N represent microbial biomass C and N and soluble C and N.

[b]Row and mid represent tree row and middle of alley.

(Figure 3), but soybean residues mineralized more N than maple and maize residues (Figure 3), which would also result in soil organic matter with a narrower C:N ratio. Moreover, N was applied annually at both sites. The addition of N may enhance plant growth and result in N enriched litter, which on decomposition may result in higher soil total N (Burkett and Dick, 1997).

Particulate organic matter fractions represent the more labile fraction of total carbon and usually constitute litter fragments in various stages of decomposition (Cambardella and Elliott 1992). Robles and Burke (1998) reported no differences in POM C and N under grasses and plant interspaces in a 6-yr-old Conservation Reserve Program (CRP) field. These authors attributed the lack of differences to the age of the CRP field and the growth habit of the rhizomatous grasses, which distribute root-derived C more evenly across the soil surface. At the pecan site, bluegrass, a rhizomatous grass, was

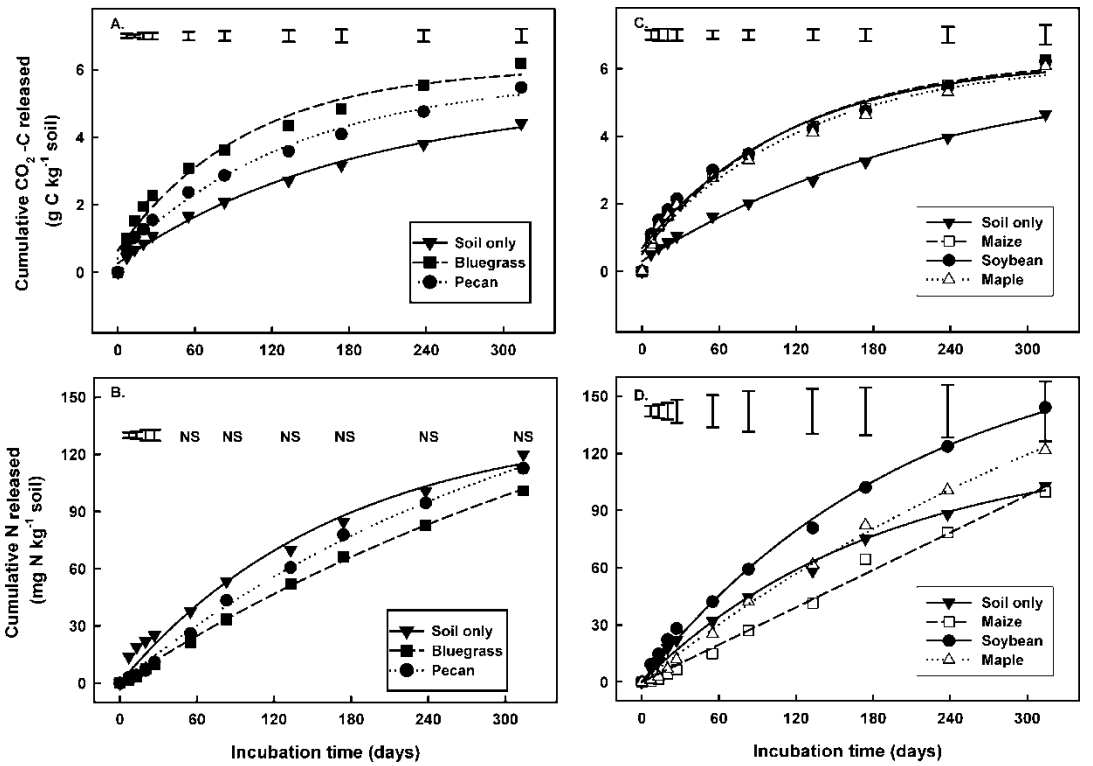

Figure 3. Carbon and nitrogen mineralization from bluegrass and pecan litter (a and b, respectively) and from maize, soybean, and maple litter (c and d, respectively). Error bars represent least significant differences at $P < 0.05$.

spread out in the alleys and under the trees, possibly explaining the lack of differences observed. POM in no-till systems accumulates on the surface (Cambardella and Elliott 1992) as confirmed by the results of this study.

Microbial biomass (MB) C and N are influenced by the amount and quality of litter (Chander et al. 1998). Cropping systems that include high-quality residues such as legumes have higher levels of MB (Franzluebbers, Hons, and Zuberer 1995). However, MB for nonleguminous (or other low-quality litter) can be improved by N fertilization to levels comparable to those including high-quality litter (Franzluebbers, Hons, and Zúberer 1995). At the maple site, maple leaf litter was of lower quality than either soybean or maize residues (Table 1), and as such when other factors are held constant, we would have expected the middle of the alley to have higher MB, especially considering the higher amounts of fertilizer (150 kg N ha^{-1}) that were applied during the maize period. The lack of difference in MB between the tree row and the middle of the alley could be attributed to microclimate modification by silver maple trees. Silver maple trees had a more closed canopy, leading to lower temperatures at the tree row that would favor microbial proliferation.

Generally the maple site had higher MBN in surface soils, which may have resulted from N fertilization. Inorganic N has been shown to increase MBN in greenhouse (Fauci and Dick 1994) and field studies (Collins, Rasmussen, and Dauglas 1992). Other authors have observed a lack of spatial differences in MB in alley cropping systems. Amatya et al. (2002) reported that MBC at 0.9 and 3.5 m from the tree row did not differ at two soil depths, 0–10 and 10–20 cm, but MBC was higher at the 0–10 cm depth in a 7-yr-old *Pinus radiata* agroforestry system in New Zealand. Similarly, soil respiration was similar between the tree row and the middle of the alley in 3- and 47-yr-old pecan–cotton alley cropping systems (Lee and Jose 2003).

CONCLUSIONS

This study hypothesized that differences in litter quality, quantity, and decomposition dynamics between trees and intercropped components would introduce spatially different trends in soil C and N fractions. These results for POM C, TOC, and TKN suggest the existence of spatially dependent patterns relative to tree rows. However, some of the other C and N fractions did not differ consistently with positions in the alley. Two reasons may explain the lack of differences. First, only the aboveground litter was quantified, whereas belowground inputs that also contribute to soil C and N fractions were not quantified. Second, the impact of the organic material present before the establishment of the alley cropping systems may have masked any effects of tree and crop inputs. Although this study does not delineate the role of trees

in temperate alley cropping systems, it does show that there were nominal spatial differences in soil C and N fractions in the two systems studied.

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